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DELAYING AN OVERHAUL & SHIP'S EQUIPMENT

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CENTER FOR NAVAL ANALYSES

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ABSTRACT

This study analyzes the effects on a ship's equipment of delaying an overhaul. Equipment condition is measured with data on 14,000 CASREPTs for destroyer-type ships in 1970-75; and regression analysis is used to measure the effects of delaying a ship's overhaul, holding constant the effects of other factors such as a ship's steaming history, class, and fleet. The frequency of CASREPTs as well as their maintenance and parts' supply times are separately analyzed. The findings suggest that delaying a ship's overhaul for one year would not adversely affect the condition of its equipment.

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DELAYING AN OVERHAUL AND SHIP'S EQUIPMENT

INTRODUCTION

The frequency of overhauls has a large effect on the Navy's operating and shipbuilding costs. In FY 1978, an overhaul for a destroyer-type ship cost $15 million, and the total expenditure for these ships -- CGs, DDGs, FFs, and FFGs -- was $525 million (reference 37, p. 59). The typical destroyer is out of service due to overhauls about 20 percent of the time, so the fleet has to be increased by that percentage to maintain effectiveness.[1]

Overhauls are done to prevent increases in equipment downtime. Unfortunately, the value of reduced downtime is difficult to measure. Still, the large costs of an overhaul would seem to be justified only if it prevents sharp increases in equipment downtime.

The purpose of this study is to estimate the effects of delaying an overhaul on a ship's equipment downtime. Not all ships are

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[1]Estimate of 18 percent was obtained from the Navy (Op-964). It is a best guess of ship unavailability due to overhauls. Due to other factors, however, actual unavailability is greater than 18 percent.

overhauled after the same months of service. This variability enables us to examine the effects of delaying an overhaul.

A CASualty REPorT or CASREPT is supposed to be filed when a ship has a serious equipment failure which impairs the ship's ability to carry out current and future assignments and which will take some measurable time to repair. Previous studies [10] and [32] have concluded that CASREPT downtime is an important indicator of equipment condition. Consequently, CASREPT data are used to measure equipment condition.

The effect of delaying an overhaul on CASREPT downtime is estimated for destroyer-type ships using regression analysis. Data on CASREPTs were obtained for 91 destroyers, cruisers, and frigates for the part of a ship's cycle that occurred after January 1970. The data are from the Navy's Consolidated CASREPT Reporting System. The sample includes observations on 10,000 less serious C2 and 4,000 more serious C3 and C4 CASREPTs for the period January 1970-July 1975.

METHOD

CASREPT downtime per month depends on the monthly CASREPT rate (C) and downtime per CASREPT. Downtime per CASREPT consists of two components: (1) supply time (S), the period a CASREPT is deferred for parts, and (2) maintenance time (M), the period a CASREPT is deferred for administrative delays and actual hands-on repairs.

As displayed in table 1, about 50 percent of CASREPTs occur because parts are unavailable. These are called "parts CASREPTs." Downtime first would consist of time waiting for parts, i.e., supply time, and then maintenance time. About 40 percent of downtime is supply time and 60 percent is maintenance time.

The other 50 percent of CASREPTs occur because the crew does not have the expertise or tools required to repair the broken equipment; in these cases downtime is all maintenance time. Equipment would be repaired with assistance of other "repair echelons," such as a tender ship (IMA), a shipyard, or an expert who is brought to the ship.[1]

---

[1]A CASREPT could also occur if administrative delays prevent equipment from being repaired within a short period. This is a more likely possibility for less serious C2 CASREPTs than it is for C3/C4s.

TABLE 1

ANALYSIS OF CASREPT DOWNTIME FOR DESTROYERS, 1970-75

CASREPT	Average number of CASREPTs per month (C)	Average hours of supply time for parts CASREPTs (S)[a]	Percent of all CASREPTs needing parts (P)	Average hours of maintenance time for all CASREPTs (M)	Average hours of downtime per CASREPT (D)[b]	Average hours of downtime per month CxD	Expected percent of downtime due to supply (.01 PS ÷ D)
C2	4.14	611	54.44	541	874	3618	38
C3/C4	1.55	454	50.78	361	592	918	39

[a] "Parts CASREPTs" are those requiring parts that were not on board.

[b] $D = .01(PS) + M$.

Source: Consolidated CASREPT Reporting System.

Through a literature review and discussions with Navy personnel, regression models for C, S, and M are specified which include time since last overhaul and other factors as explanatory variables. Estimates of the effects of delaying an overhaul on C, S, and M are obtained from the regression models. These are used to calculate the effects on CASREPT downtime of delaying an overhaul for one year.

CASREPT RATE

Regression Model Specification

Direct determinants of the CASREPT rate are listed below together with the expected direction of their effects.

1. Past utilization of equipment (+)
2. Current utilization of equipment (+)
3. Age of equipment (+)
4. Degree of equipment complexity (+)
5. Favorable external conditions (-)
6. Condition of equipment after overhaul (-)
7. Training of personnel (-)
8. Number of equipment starts (+)
9. Initial stock of parts on board (-)
10. Funds allowance for parts (-)
11. Willingness of command to report CASREPTs (+)

Data are unavailable on most of these determinants. To overcome data problems, we identifed relationships between them and measurable explanatory variables, which are given below. If we

could identify it, the direction of an explanatory variable's effect on a direct determinant is indicated. We also include "number of months since Jan 1970" to test for time trends.

1. Past utilization of equipment (+):
   - Past steaming underway (+)[1]
   - Past steaming not underway (+)
   - Time since overhaul (+)

2. Current utilization of equipment (+):
   - Current steaming underway (+)
   - Current steaming not underway (+)

3. Age of equipment (+):
   - Time since overhaul (+)

4. Degree of equipment complexity (+):
   - Ship class (?)

5. Favorable external conditions (-):
   - No measurable explanatory variables identified

6. Good condition of equipment after overhaul (-):
   - Atlantic or Pacific Fleet (?)

7. Training of personnel (-):
   - Current steaming underway (+)
   - Current steaming not underway (+)
   - Past steaming underway (+)
   - Past steaming not underway (+)
   - Time since overhaul (+)

8. Number of equipment starts (+):
   - No data available

9. Stock of parts on board (-):

---

[1]The number of hours steaming underway is a measure of operating tempo: the crew is relatively active operating the ship and undertaking training exercises. Hours steaming not underway are periods of relative inactivity. Although energy needs are met from its own boilers, a ship's systems are operated at a slower pace and the crew undertakes fewer training exercises. Hours not steaming are periods of minimum activity: a ship's boilers are turned off and energy is provided from shore through an electrical hookup.

Fleet (?)
Time since overhaul (-)

10. Funds allowance for parts (-):
    Fleet (?)

11. Willingness of command to report CASREPTs (+):
    Fleet (?)
    Point in the deployment cycle:
        Months 1, 2, 3 and 4 after overhaul (+)
        Months 1, 2, 3 and 4 prior to overhaul (-).

The definitions, means and standard deviations of regression variables are given in table 2. Except for the dummy variables, months 1, 2, 3 and 4 before and after overhaul, the direction of a regression variable's effect cannot be predicted a priori, a result which may not critically depend on our particular specification of relationships between explanatory variables and determinants.[1] Signs of regression variables, such as time since overhaul, past steaming underway, etc., are ambiguous because each is related to several direct determinants which have different effects qualitatively. These real world complexities make it impossible to understand the reasons for the measured effect of a regression variable.

Findings

Pooled time series cross section data on 2468 ship-months are used to analyze the CASREPT rate for C2 and C3/C4 CASREPTs. Regression

---

[1]An alternative system of relationships would probably also yield ambiguous theoretical results.

TABLE 2

DEFINITIONS, MEAN VALUES AND STANDARD DEVIATIONS OF CASREPT RATE MODEL VARIABLES

Variables	Mean values	Standard deviations
Monthly number C2 CASREPTs	4.14	3.61
Monthly number C3/C4 CASREPTs	1.55	1.89
Monthly steaming hours underway	247.8	197.2
Total past steaming hours underway since overhaul	5576.7	2996.5
Monthly steaming hours not underway	139.4	131.2
Total past hours steaming not underway since overhaul	3653.0	2306.4
Number of months since Jan 1970	20.4	12.3
Number of months since overhaul	22.1	12.0
Overhaul cycle variables:		
One if first month after overhaul, zero otherwise	0.016	.12
One if second month after overhaul, zero otherwise	0.017	.13
One if third month after overhaul, zero otherwise	0.017	.13
One if fourth month after overhaul, zero otherwise	0.017	.13
One if first month before overhaul, zero otherwise	0.034	.18
One if second month before overhaul, zero otherwise	0.034	.18
One if third month before overhaul, zero otherwise	0.034	.18
One if fourth month before overhaul, zero otherwise	0.033	.18
Ship classes:		
FRAMS: Benchmark ship class	0.32	.47
DD 931	0.079	.27
DDG 2	0.18	.38
DDG 31	0.019	.14
DDG 35	0.018	.13
DDG 40	0.0073	.085
FF 1036 One if in ship class, zero otherwise	0.0073	.085
FF 1037	0.073	.26
FF 1040	0.095	.29
FF 1052	0.041	.20
FFG 1	0.026	.16
CG 16	0.049	.22
CG 26	0.084	.28
Fleet: one if Atlantic, zero otherwise	0.48	.50

results, given in table 3, are obtained using the ordinary least squares estimation procedure.

The F statistics indicate both regressions are statistically significant at the .01 level. The R^2s of 0.14 for C2 and 0.096 for C3/C4 CASREPTs are low, which is not unusual for models estimated with time series cross section data. The low R^2 values indicate a large fraction of serious equipment failures is still random, but some of it can be explained.

The "elasticity" is the percent change in a dependent variable due to a one percent change in an explanatory variable. If the elasticity equals one in absolute value, a variable has a proportional effect, e.g., if x changes by 10 percent y also changes by 10 percent. Estimates of elasticities are included, where applicable, to help one determine the relative importance of a regression variable's effect.[1]

A number of variables are statistically significant and have large elasticities. Our most important findings are that past steaming and time since overhaul have large but opposite effects, and that Atlantic fleet ships have higher CASREPT rates.

---

[1]Due to rounding, elasticities computed by the reader may differ slightly from those reported in the tables.

TABLE 3

CASREPT RATE REGRESSION FINDINGS

	CASREPTS			
	C2		C3/C4	
Variable	Effect[a]	Elasticity[b]	Effect[a]	Elasticity[b]
Current hours steaming underway per month	.00216 (5.75)[c]	.129	.00008 (.39)	.012
Total past steaming hours underway since overhaul	-.00049 (6.52)[c]	-.661	-.00018 (4.39)[c]	-.639
Current hours steaming not underway per month	.00143 (2.45)[c]	.048	.00104 (3.30)[c]	.092
Total past hours steaming not underway since overhaul	-.00013 (1.63)	-.114	-.00001 (.22)	-.022
Number of months since Jan 1970	-.00205 (.22)	-.010	.00128 (.26)	.016
Number of months since overhaul	.12909 (5.42)[c]	.688	.05842 (4.57)[c]	.831
Dummy variables:				
First month after overhaul	1.11332 (1.95)[c]		.45678 (1.49)	
Second month after overhaul	.06988 (.12)		.27744 (.93)	
Third month after overhaul	(-.29071 (.53)		.03801 (.12)	
Fourth month after overhaul	-.07861 (.14)		-.28703 (.98)	

TABLE 3 (Cont'd)

Variables	CASREPTS C2 Effect[a]	CASREPTS C3/C4 Effect[a]
First month before overhaul	-2.11825 (5.23)[c]	-.83522 (3.84)[c]
Second month before overhaul	-1.07911 (2.72)[c]	-.47636 (2.23)[c]
Third month before overhaul	-.73260 (1.86)[c]	-.58172 (2.76)[c]
Fourth month before overhaul	-.50262 (1.27)	-.11158 (.54)
DD 931	1.81859 (6.65)[c]	.00901 (.06)
DDG 2	1.23585 (5.39)[c]	.05894 (.47)
DDG 31	.76626 (1.41)	-.19032 (.65)
DDG 35	.88488 (1.64)	.27104 (.94)
DDG 40	-2.20916 (2.43)[c]	-1.23961 (2.54)[c]
FF 1036	.84500 (1.03)	-.62049 (1.41)

TABLE 3 (Cont'd)

Variable	CASREPTS C2 Effect[a]	CASREPTS C3/C4 Effect[a]
FF 1037	-.83358 (2.55)[c]	-.03722 (.21)
FF 1040	-.83242 (2.79)[c]	-.10882 (.68)
FF 1052	-.95217 (2.36)[c]	.84612 (3.92)[c]
FFG 1	1.27900 (2.68)[c]	1.16820 (4.57)[c]
CG 16	1.55460 (4.38)[c]	.28217 (1.48)
CG 26	1.00975 (3.58)[c]	.36707 (2.42)[c]
Fleet	.092258 (5.60)[c]	.61665 (6.98)[c]
Constant	3.11	.76
Summmary Statistics		
F(27,2440)	14.76	9.57
R^2	.14	.096

Sources: Steaming and Fuel Data Master Files and Consolidated CASREPT Reporting Systems

[a]t-values given in parentheses.

[b]Calculated at the arithmetic means.

[c]Statistically significant at .05 level.

Months since overhaul has a statistically significant and positive effect: about 0.129 for C2 and 0.058 for C3/C4 CASREPTs. If other factors were held fixed, the C3/C4 CASREPT rate would increase over time according to the formula

$$\Delta C3/C4 = 0.058 \Delta t \qquad (1)$$

where t = months since overhaul.

In 1970-75, an overhaul for these ships was undertaken after about 3.5 years of service. If it was delayed for one year, the increase in the number of C3/C4 CASREPTs over the year would be given by

$$\Delta C3/C4^{T} = 0.058 \sum_{t=1}^{12} \Delta t = 4.52 \qquad (2)$$

However, to estimate the net effect of delaying an overhaul, we must include the effects of all variables that change over time, i.e., past steaming underway, past steaming not underway, and time since 1970. Using average steaming rates per month to estimate increases in past steaming variables, equations (1) and (2) become

$$\Delta C2 = -0.0126\Delta t \tag{3a}$$

$$\Delta C3/C4 = 0.0138\Delta t \tag{3b}$$

and

$$\Delta C2^T = -0.0126\sum_{\Delta t=1}^{12} \Delta t = -0.98 \tag{4a}$$

$$\Delta C3/C4^T = 0.0138\sum_{\Delta t=1}^{12} \Delta t = 1.07 \tag{4b}$$

Using equation (4b), we estimate that if an overhaul were delayed for a year there would be only about one more C3/C4 CASREPT. Using equation (4a), we estimate there would be a decline of about one C2 CASREPT. The results have the following implication: if an overhaul were undertaken after 4.5 years instead of 3.5, there would not be a serious deterioration of equipment condition because of increases in the number of CASREPTs.[1]

---

[1]Our results would be invalid if ships with higher CASREPT rates were overhauled first, i.e., earlier in their cycles. However, we know of no evidence that a ship's CASREPT rate was considered as a factor in the scheduling of overhauls.

MAINTENANCE DOWNTIME PER CASREPT

Regression Model Specification

Direct determinants of maintenance per CASREPT are listed below together with the expected direction of their effects.

1. Operating demands for ship maintenance (+)
2. Quality and quantity of ship's maintenance personnel (-)
3. Whether CASREPT for parts (-)
4. Degree of equipment complexity (+)
5. Technical difficulty of required maintenance (+)
6. Supply of intermediate level maintenance resources (-)
7. Supply of ship's other maintenance resources (-)
8. Whether repaired off ship (+)
9. Whether period of overhaul quality control (+)[1]

As in the CASREPT rate analysis, to overcome data problems we identified relationships between direct determinants and measurable explanatory variables. These relationships are given below. If we could identify it, the direction of an explanatory variable's effect on a direct determinant is indicated.

1. Operating demands for maintenance personnel (+):
   - Current steaming underway (+)
   - Past steaming underway (-)
   - Current steaming not underway (+)
   - Past steaming not underway (-)
   - Whether a C3/C4 CASREPT (-)

2. Supply of maintenance personnel (-):
   - Past steaming underway (+)
   - Current steaming underway (+)

---

[1]Just after an overhaul there may be a quality control period during which personnel spend extra time repairing CASREPTs.

Past steaming not underway (+)
Current steaming not underway (?)
Whether C3/C4 CASREPT (+)
Time since overhaul (+)

3. Whether CASREPT for parts (-):
   Measured directly by whether a CASREPT had any supply downtime

4. Degree of equipment complexity (+):[1]
   Past steaming underway (?)
   Past steaming not underway (?)
   Repair echelon (?)
   Ship class (?)
   Time since overhaul (?)

5. Technical difficulty of required maintenance (+):
   Current steaming underway (?)
   Current steaming not underway (?)
   Repair echelon (?)
   Ship class (?)
   Time since overhaul (?)

6. Supply of intermediate level maintenance resources (-):
   Fleet (?)

7. Supply of ship's other maintenance resources (e.g., diagnostic equipment, etc.) (-):
   No explanatory variable identified

8. Repaired off ship (+)
   Repair echelon (+)

9. Whether period of overhaul quality control (+)
   Months 1,2,3, and 4 after overhaul (+)

The result is a regression model having the variables listed in tables 4 and 5. We also include "number of months since January 1970" to test for a time trend.

[1]Average equipment complexity for a CASREPT depends on the number and mix of CASREPTs among subsystems. We assume it is measured by the factors listed.

TABLE 4

DEFINITIONS, MEAN VALUES AND STANDARD DEVIATIONS
OF C2 MAINTENANCE DOWNTIME MODEL VARIABLES

Variables	Mean values	Standard deviations
Hours of C2 CASREPT downtime due to maintenance	540.8[a]	1089.7
Ratio of hours steaming underway to maintenance downtime (current steaming underway)	.318	.249
Total hours of steaming in months before CASREPT (in thousands)	5.054	2.902
Ratio of hours steaming not underway to maintenance downtime (current steaming not underway)	.198	.174
Total hours of steaming not underway in months before CASREPT (in thousands)	3.545	2.249
Months since Jan 1970	19.4	11.8
Months since overhaul	20.8	11.7
The following are dummy variables:		
If there was any downtime due to supply = 1	.54	.50
Ship classes:		
FRAM: Benchmark class	.29	.45
DD 931	.10	.31
DDG 2	.21	.41
DDG 31	.018	.13
DDG 35	.019	.14
FF 1036	.0026	.051
FF 1037	.0074	.086
FF 1040	.058	.23
FF 1052	.074	.26
FFG 1	.028	.16
DDG 40	.031	.17
CG 16	.063	.24
CG 26	.092	.29
Repair echelon:		
Repair by ship's crew is benchmark echelon	.55	.50
If repaired with technical assistance = 1	.19	.39
If repaired at IMA = 1	.26	.44
If repaired at overhaul = 1	.0014	.037
If repaired at drydock = 1	.0020	.044
Months since overhaul dummy variables:		
One month after overhaul	.0015	.038
Two months after overhaul	.0020	.044
Three months after overhaul	.0020	.044
Four months after overhaul	.0025	.050
Fleet: 1 if Atlantic, 0 if Pacific	.52	.50

[a]Geometric mean is 143.9

TABLE 5

DEFINITIONS, MEAN VALUES AND STANDARD DEVIATIONS OF C3/C4 MAINTENANCE DOWNTIME MODEL VARIABLES

Variables	Mean values	Standard deviations
Hours of C3/C4 CASREPT downtime due to maintenance	361.0[a]	735.5
Ratio of hours steaming underway to maintenance downtime (current steaming underway)	.303	.243
Total hours of steaming in months before CASREPT (in thousands)	5.325	2.970
Ratio of hours steaming not underway to maintenance downtime (current steaming not underway)	.197	.177
Total hours of steaming not underway in months before CASREPT (in thousands)	3.747	2.401
Months since Jan 1970	20.29	12.3
Months since overhaul	22.25	12.4
The following are dummy variables:		
If there was any downtime due to supply = 1	.51	.50
Ship classes:		
FRAM: Benchmark class	.32	.47
DD 931	.078	.27
DDG 2	.18	.38
DDG 31	.0098	.098
DDG 35	.018	.13
FF 1036	.0005	.022
FF 1037	.0023	.048
FF 1040	.071	.26
FF 1052	.077	.27
FFG 1	.051	.22
DDG 40	.046	.21
CG 16	.058	.23
CG 26	.094	.29
Repair echelon:		
Repair by ship's crew is benchmark echelon	.48	.50
If repaired with technical assistance = 1	.23	.42
If repaired at IMA = 1	.28	.45
If repaired at overhaul = 1	.0018	.042
If repaired at drydock = 1	.0008	.028
Months since overhaul dummy variables:		
One month after overhaul	.0015	.039
Two months after overhaul	.0023	.048
Three months after overhaul	.0021	.045
Four months after overhaul	.0010	.032
Fleet: 1 if Atlantic, 0 if Pacific	.57	.50

[a]Geometric mean is 111.9

Except for the dummy variables, whether CASREPT for parts (-), whether a C3/C4 CASREPT (-), and months 1, 2, 3 and 4 after overhaul (+), the direction of an explanatory variable's effect cannot be predicted, and it is impossible to identify the reasons for its effect on maintenance downtime.

The distribution of maintenance downtime has a "long tail" -- a few maintenance actions take a long time. The time for most is clustered around the geometric rather than the arithmetic mean. Because of the distribution's skewness, the natural logarithm rather than the actual level of maintenance downtime per CASREPT is regressed on explanatory variables.[1]

Findings

Pooled time series cross section data on 10,225 C2 and 3,785 C3/C4 CASREPTs are used to analyze maintenance downtime per CASREPT. Regression results, given in table 6, are obtained using the ordinary least squares estimation procedure.

The F statistic indicates the regression is statistically significant at the .01 level. An R^2 of 0.24 for C2 and 0.21 for C3/C4

---

[1]Although not reported, we also estimate the model using the actual level of maintenance downtime per CASREPT. As expected the log model provided a better fit. For discussion of the statistical procedure used to determine which model better fit the data, see [28], pp. 107-111.

TABLE 6

MAINTENANCE REGRESSION FINDINGS

Variable	CASREPTs C2 Effect[a]	CASREPTs C2 Elasticity[b]	CASREPTs C3/C4 Effect[a]	CASREPTs C3/C4 Elasticity[b]
Ratio of hours steaming underway to maintenance downtime	-.67988 (10.82)[c]	-.213	-1.10619 (10.66)[c]	-.321
Total hours of steaming underway before CASREPT	.02722 (1.63)	.137	.11828 (4.40)[c]	.629
Ratio of hours steaming not underway to maintenance downtime	-.51621 (5.46)[c]	-.101	-.37973 (2.46)[c]	-.074
Total hours of steaming not underway before CASREPT	.02257 (1.28)	.080	.01206 (.43)	.045
Months since Jan 1970	.00632 (3.26)[c]	.122	.00157 (.48)	.031
Months since overhaul	-.00650 (1.20)	-.135	-.02142 (2.63)[c]	-.476
Dummy variables:				
If any downtime due to supply = 1	-1.33249 (41.50)[c]		-1.01228 (19.98)[c]	
Ship class:				
DD 931	.15594 (2.88)[c]		.14717 (1.52)	
DDG 2	-.14306 (2.93)[c]		-.13436 (1.62)	

TABLE 6 (Cont'd)

	CASREPTs	
	C2	C3/C4
Variable	Effect[a]	Effect[a]
DDG 31	-.28042 (2.30)[c]	-.32662 (1.28)
DDG 35	-.13927 (1.22)	.32846 (1.73)
FF 1036	-.19724 (.65)	-.87681 (.82)
FF 1037	-.19675 (1.10)	-.21466 (.42)
FF 1040	-.00973 (.12)	.11844 (1.03)
FF 1052	.05546 (.79)	-.16780 (1.49)
FFG 1	-.08412 (.83)	-.21390 (1.61)
DDG 40	.16956 (1.72)	.06251 (.45)
CG 16	-.22091 (3.10)[c]	-.07222 (.60)
CG 26	-.05083 (.82)	-.20530 (2.10)[c]

TABLE 6 (Cont'd)

	CASREPTs	
	C2	C3/C4
Variable	Effect[a]	Effect[a]
Repair echelon:		
Technical assistance	.39163 (9.64)[c]	.52283 (8.54)[c]
IMA	.49122 (13.04)[c]	.52660 (8.72)[c]
Overhaul	.69615 (1.73)	.26901 (.47)
Drydock	2.11088 (6.29)[c]	1.56509 (1.81)
Months after overhaul dummy variables:		
One month after overhaul	.55523 (1.43)	.41466 (.67)
Two months after overhaul	.08933 (.26)	-.16197 (.32)
Three months after overhaul	-.21190 (2.0)[c]	-.08436 (.15)
Four months after overhaul	-.07052 (.23)	1.96058 (2.63)[c]
Fleet: 1 if Atlantic, 0 if Pacific	.05236 (1.43)	.04801 (.80)

TABLE 6 (Cont'd)

Variable	C2 Effect[a]	C3/C4 Effect[a]
Constant	5.70	5.15
Summary statistics:		
F	$F(28,10196) = 117.21$	$F(28,3866) = 36.09$
R^2	.24	.21

Sources: Steaming and Fuel Data Master Files and Consolidated CASREPT Reporting Systems.

[a]t-values given in parentheses.

[b]Calculated at the geometric means of maintenance downtime per CASREPT and arithmetic mean of explanatory variables.

[c]Statistically significant at the .05 level.

CASREPTs indicates a small proportion of the variation in maintenance downtime per CASREPT is explained by our variables.

To test whether C3/C4 CASREPTs had less maintenance downtime than C2 CASREPTs, we pooled the data and included a dummy variable for C3/C4 CASREPTs. The results indicate that C3/C4 CASREPTs have less maintenance downtime. The effect is statistically significant at the .05 level. These results may be because of shorter administrative delay times for C3/C4 CASREPTs.

The regression model is statistically significant, but it explains only a small percent of the variation in maintenance downtime per CASREPT. Time since overhaul has a negative effect. Past steaming underway and past steaming not underway increase maintenance downtime, while current steaming underway and current steaming not underway reduce it.[1] Maintenance time was much lower for CASREPTs that had to wait for parts and C3/C4 CASREPTs. CASREPTs repaired off ship had more maintenance time. While ship classes had some effects, fleet and cycle dummy variables had none. Finally, maintenance downtime seems to be increasing over time.

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[1]To measure steaming intensity during the life of a CASREPT, which could be days, weeks, or months, we divided steaming hours during the CASREPT's maintenance period by maintenance time. Thus, "current steaming" for a CASREPT's maintenance period is a ratio: hours steaming (either underway or not underway) to hours of maintenance downtime. In the CASREPT rate analysis, "current steaming" is hours of steaming during the month observed.

Although time since overhaul is negatively related to maintenance downtime per CASREPT, other factors are positively related. The net effect of delaying an overhaul is to increase maintenance time per CASREPT:[1]

$$\Delta M = 1.40\Delta t \qquad \text{C2 CASREPTs} \qquad (5a)$$

$$\Delta M = 1.25\Delta t \qquad \text{C3/C4 CASREPTs} \qquad (5b)$$

If an overhaul were delayed for one year, maintenance downtime per CASREPT during the extended period would increase; on average, the increase would be 8.4 hours for C2 CASREPTs and 7.5 hours for C3/C4s.[2]

SUPPLY DOWNTIME PER CASREPT

Regression Model Specification

As in the previous two subsections, direct determinants are listed first together with the expected direction of their effects.

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[1]Estimated by multiplying $\frac{dM}{M}/dt$ times the geometric mean of M. The geometric mean is used because lnM rather than the level of M is the dependent variable in the regression model.

[2]Estimates obtained by evaluating equations (5a) and (5b) at the midpoint (6 months) of the additional year.

1. Parts required per CASREPT (+)
2. Amount of parts reordered (+)
3. Inventory of parts stocked by suppliers (-)
4. Frequency of deliveries from supplies (-)
5. Availability of funds for repair parts (-)

Again, to overcome data problems we identified relationships between direct determinants and measurable factors. These are given below.

1. Parts required per CASREPT (+):
   - Past steaming underway (?)
   - Past steaming not underway (?)
   - Ship class (?)
   - Time since overhaul (?)

2. Amount of parts reordered (+):
   - Past steaming underway (?)
   - Repair echelon (?)
   - Past steaming not underway (?)
   - Ship class (?)
   - Time since overhaul (?)
   - Current steaming underway (?)
   - Current steaming not underway (?)
   - Whether C3/C4 CASREPT (-)

3. Inventory of parts stocked by suppliers (-):
   - Ship class (?)
   - Fleet (?)

4. Frequency of deliveries from suppliers (-):
   - Current steaming underway (-)
   - Fleet (?)
   - Whether C3/C4 CASREPT (+)

5. Special parts requirements (?):
   - Repair echelon (?)
   - Ship class (?)

These variables are listed in tables 7 and 8. We also include the logarithm of the number of months since January 1970 to test for a

TABLE 7

DEFINITIONS, MEAN VALUES AND STANDARD DEVIATIONS
OF C2 SUPPLY TIME MODEL VARIABLES

Variables	Mean values	Standard deviations
Hours of C2 CASREPT downtime due to supply	611.0[a]	835.8
Ratio of hours steaming underway to CASREPT downtime	.361	.235
Total hours of past steaming before CASREPT (in thousands)	3.325	2.575
Ratio of hours steaming not underway to CASREPT downtime	.226	.150
Total hours of past steaming not underway before CASREPT (in thousands)	2.211	1.474
Logarithm of months since Jan 1970	2.7	.90
Months since overhaul	15.3	8.53
Ship classes:		
FRAM: Benchmark class	.27	.44
DD 931	.10	.30
DDG 2	.21	.41
DDG 31	.018	.13
DDG 35	.018	.13
FF 1036	.0025	.050
FF 1037	.0050	.070
FF 1040	.060	.24
FF 1052	.062	.24
FFG 1	.026	.16
DDG 40	.031	.17
CG 16	.077	.27
CG 26	.11	.32
Repair echelon:		
Repair by ship's crew is benchmark echelon	.71	.45
If repaired with technical assistance = 1, 0 otherwise	.15	.36
If repaired at IMA = 1, 0 otherwise	.14	.35
If repaired at overhaul = 1, 0 otherwise	.0005	.022
Fleet: 1 if Atlantic, 0 otherwise	.56	.50

[a]Geometric mean is 311.0.

TABLE 8

DEFINITIONS, MEAN VALUES AND STANDARD DEVIATIONS
OF C3/C4 SUPPLY TIME MODEL VARIABLES

Variables	Mean values	Standard deviations
Hours of C3/C4 CASREPT downtime due to supply	454.1[a]	679.6
Ratio of hours steaming underway to CASREPT downtime	.339	.235
Total hours of steaming in months before CASREPT (in thousands)	3.761	2.558
Ratio of hours steaming not underay to CASREPT downtime	.213	.145
Total hours of steaming not underway in months before CASREPT (in thousands)	2.458	1.666
Logarithm of months since Jan 1970	2.80	.80
Months since overhaul	17.2	9.5
Ship classes:		
FRAM: Benchmark class	.28	.45
DD 931	.056	.23
DDG 2	.17	.38
DDG 31	.0076	.086
DDG 35	.021	.14
FF 1036	.0009	.030
FF 1037	.0014	.038
FF 1040	.080	.27
FF 1052	.066	.24
FFG 1	.049	.21
DDG 40	.048	.21
CG 16	.068	.25
CG 26	.13	.34
Repair echelon:		
Repair by ship's crew is benchmark echelon	.61	.49
If repaired with technical assistance = 1, 0 otherwise	.21	.41
If repaired at IMA = 1, 0 otherwise	.16	.37
If repaired at overhaul = 1, 0 otherwise	.0014	.037
Fleet: 1 if Atlantic, 0 otherwise	.62	.48

[a]Geometric mean is 224.1.

time trend.

Although a C3/C4 CASREPT should have fewer hours of supply downtime, the direction of other variables' effects could not be predicted. As before, by specifying theoretical relationships we can identify explanatory variables but not the direction of their effects a priori, and we cannot explain the reason for a regression variable's measured effect.

Like maintenance downtime, the distribution of supply downtime has a "long tail" -- a few take a long time. The time for most is clustered around the geometric rather than the arithmetic mean. Because of the skewness of the distribution, the natural logarithm rather than the actual level of supply downtime per CASREPT is regressed on explanatory variables.[1]

Findings

Pooled time series cross section data on 6,008 C2 and 2,110 C3/C4 CASREPTs are used to analyze supply downtime. Regression results, given in table 9, are obtained using the ordinary least squares estimation procedure.

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[1]Although not reported, we also estimate the model using the actual level of supply downtime per CASREPT. As expected, the log model provided a better fit, although neither model fit the data well.

TABLE 9

SUPPLY TIME REGRESSION FINDINGS

	CASREPTs			
	C2		C3/C4	
Variable	Effect[a]	Elasticity[b]	Effect[a]	Elasticity[b]
Ratio of hours steaming underway to CASREPT downtime	-.07168 (.98)	-.025	-.15834 (1.24)	-.053
Total hours of past steaming before CASREPT	.00000 (.12)	.000	.05000 (1.66)	.188
Ratio of hours steaming not underway to CASREPT downtime	-.00451 (4.18)[c]	-.001	-.33135 (1.79)	-.070
Total hours of past steaming not underway before CASREPT	-.01719 (.32)	-.038	-.07000 (1.83)	-.172
Logarithm of months since Jan 1970[d]	-.00217 (2.52)[c]	-.002	.05603 (.89)	.056
Months since overhaul	.00040 (.06)	.006	-.00309 (.29)	-.053
Dummy variables:				
Ship classes:				
DD 931	.16575 (2.74)[c]		-.06950 (.53)	
DDG 2	-.05885 (1.16)		-.55910 (.60)	
DDG 31	.29846 (2.25)[c]		.23994 (.71)	

TABLE 9 (Cont'd)

Variable	CASREPTs C2 Effect[a]	CASREPTs C3/C4 Effect[a]
DDG 35	.14450 (1.12)	.21670 (1.06)
FF 1036	-.22032 (.66)	-.68137 (.74)
FF 1037	-.38052 (1.62)	.48639 (.64)
FF 1040	.09626 (1.26)	-.25320 (2.13)[c]
FF 1052	.14281 (1.81)	-.06640 (.50)
FFG 1	.04844 (.43)	-.07068 (.45)
DDG 40	.37744 (3.67)[c]	.40507 (2.69)[c]
CG 16	.24812 (3.50)[c]	.16448 (1.27)
CG 26	.18639 (2.94)[c]	.20658 (1.96)[c]

TABLE 9 (Cont'd)

	CASREPTs	
	C2	C3/C4
Variable	Effect[a]	Effect[a]
Repair echelon:		
Technical assistance	.00595 (.12)	.12360 (1.754)
IMA	.19972 (4.13)[c]	.01617 (.2049)
Overhaul	.20069 (.27)	-.09413 (.1261)
Fleet: 1 if Atlantic, 0 if Pacific	.017895 (4.47)[c]	.16651 (2.397)[c]
Constant	5.43	5.26
Summary statistics:		
F	F(22,5985) = 6.66	F(22,2087) = 2.10
R^2	.024	.022

Source: Steaming and Fuel Data Master Files and Consolidated CASREPT Reporting Systems

[a]t-values given in parentheses.

[b]Elasticity evaluated at geometric mean for supply time and arithmetic mean for explanatory variables.

[c]Statistically significant at .05 level.

[d]Used logarithm of time variable to reduce multicollinearity with months since overhaul.

The models explain almost none of the variation in supply downtime. Although there are statisticaly significant relationships, the R^2 is only 0.024 for C2 and 0.022 for C3/C4 CASREPTs.

To test whether C3/C4 CASREPTs had less supply downtime, we pooled the data and included a dummy variable for C3/C4 CASREPTs. The results indicate that C3/C4 CASREPTs have less supply downtime. The impact is statistically significant at the .05 level. These results may be because parts are shipped more quickly for C3/C4 CASREPTs.

Supply time seems to be largely unaffected by explanatory variables, including time since overhaul. Although C3/C4 CASREPTs have less supply downtime, most explanatory factors are not significant. We find evidence, however, that Atlantic fleet ships have more downtime because of supply related factors.[1]

The net effect of delaying an overhaul is to increase supply time per CASREPT:

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[1]Perhaps our most interesting finding is the positive sign of Atlantic fleet, which is statistically significant for both C2 and C3/C4 CASREPTs. From the CASREPT rate analysis, we find Atlantic fleet ships had more CASREPTs. To see if this is because of supply problems, we look at the simple correlation between variables "whether CASREPT for parts" (from the maintenance time regression model) and Atlantic fleet. We find a positive correlation of 0.08, which indicates that Atlantic fleet ships had relatively more CASREPTs because parts were unavailable than did ships in the Pacific fleet.

$$\Delta S = -0.66\ \Delta t \qquad \text{C2 CASREPTs} \tag{6}$$

$$\Delta S = 0.74\ \Delta t \qquad \text{C3/C4 CASREPTs} \tag{7}$$

If the overhaul were delayed for one year, supply time per CASREPT would on the average decrease by 4.0 hours for C2 CASREPTs and increase by 4.4 hours for C3/C4s.

DELAYING OVERHAULS AND CASREPT DOWNTIME

The effects on CASREPT downtime of delaying an overhaul for one year are given in table 10. In the additional year, downtime increases by 864 hours for C3/C4 CASREPTs. This represents only a 6.3 percent increase compared to the number of hours that would have occurred had the overhaul taken place in the previous year. Downtime declines by 692 hours for C2 CASREPTs, a slight drop of 1.6 percent. Thus, downtime is hardly affected by extending the ship's cycle for one year.

TABLE 10

EFFECTS ON CASREPT DOWNTIME OF DELAYING AN OVERHAUL FOR ONE YEAR[a]

Type of CASREPT	Annual change in the number of CASREPTs	Change in hours of maintenance time per CASREPT	Change in hours of supply time for parts CASREPTs	Annual change in expected hours of CASREPT downtime: Actual	Annual change in expected hours of CASREPT downtime: Percent
C2	-1 (48)	+8.4 (560)	-4.0 (600)	-673 (43,315)	-1.6
C3/C4	1 (21)	+7.5 (380)	+4.4 (460)	864 (13,730)	+6.3

[a]Numbers in parentheses are estimated values of C, M, S, and CASREPT downtime in the year prior to overhaul (rather than at the midpoint of the observations given in earlier tables). They are the base levels to which the changes given in the table must be added to yield values of C, M, S, and CASREPT downtime in the last year prior to a ship's overhaul.

CONCLUSIONS

This study provides evidence which suggests that overhauls of destroyers may have been undertaken too frequently in 1970-75. The typical ship was overhauled after just 3.5 years of service. Those overhauled later had only slightly more C3/C4 CASREPT downtime; they also had slightly <u>less</u> C2 CASREPT downtime. Consequently, if destroyers are overhauled after just 3.5 years of service, the benefits do not seem to justify the large direct costs, plus the costs of building and operating additional ships to compensate for the unavailability of those in overhaul.[1]

Since 1970-75, the policy of the Navy has been to extend ships' cycles to some degree. The Navy should continue this policy of extending them, until it is clear that an overhaul is undertaken when the benefits justify the costs.

Our study may be limited for two reasons. First, a typical ship's cycle is now longer than it was in 1970-75, and we would not want to extrapolate our findings beyond the range of most observations. However, the Navy is now undertaking more scheduled maintenance while a ship is in service. This should prevent increases in the

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[1]Instead, programs aimed at increasing the availability of parts and the capability of maintenance personnel might be more cost effective in reducing CASREPT downtime. However, evidence on the effects of such programs is highly tentative or unavailable. See [3], [9], and [10].

number of equipment failures, so further extending ships' cycles may still be appropriate. Second, CASREPT data measure only serious equipment failures that cannot be repaired quickly. This leaves out less serious equipment failures and serious ones that are repaired within a short period; perhaps the number of these failures increase over time.

The Navy should measure the relationship between the failure rate of all equipment and time since overhaul for ships operating under the new maintenance system, and use this information in determining when to schedule ships for overhauls.

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